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ULTRASONIC WELD BONDING OF HELICOPTER PRIMARY
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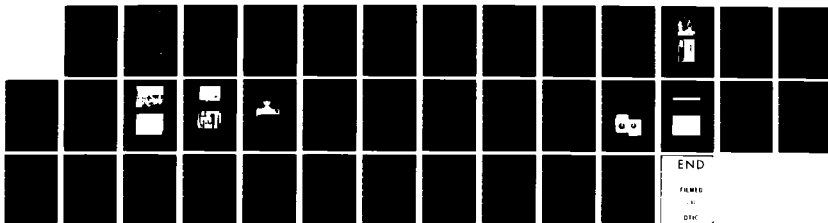
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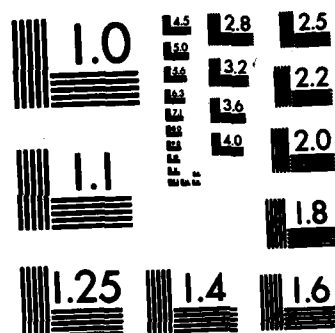
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**ULTRASONIC WELD BONDING OF HELICOPTER PRIMARY
STRUCTURES**

**K. K. Niji
HUGHES HELICOPTERS, INC.
Centinela and Teale St.
Culver City, Calif. 90230**

December 1982

Final Report for Period September 1979 - July 1981

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Prepared for

APPLIED TECHNOLOGY LABORATORY

U. S. ARMY RESEARCH AND TECHNOLOGY LABORATORIES (AVRADCOM)

Fort Eustis, Va. 23604

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APPLIED TECHNOLOGY LABORATORY POSITION STATEMENT

This project was accomplished as part of the US Army Aviation Research and Development Command Manufacturing Technology program. The primary objective of this program was to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army material. This report identifies the results of an investigation to develop and optimize an ultrasonic weld bonding procedure for the fabrication of primary structural components for helicopters. It was determined that the surface condition required for good adhesive bonding was not compatible with that required for good ultrasonic welding.

Robert L. Rodgers of the Aeronautical Technology Division served as project engineer for this effort.

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| 20. ABSTRACT (Continue on reverse side if necessary and identify by block number) This program was a study to develop and optimize an ultrasonic weld bonding procedure for the fabrication of primary structural components for helicopters. This procedure, a combination of ultrasonic welding and adhesive bonding, was studied through a series of coupon tests. Various adhesives and surface treatments were evaluated with regard to their adaptability to ultrasonic weld bonding. Adhesive bond quality and weld | | |

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20. ABSTRACT (CONT)

quality were evaluated through various T-shear, fatigue, and environmental salt-spray tests. Environmental degradation of the adhesively bonded areas occurred consistently and could not be resolved.

It was determined that the surface condition required for good adhesive bonding was not compatible with that required for good ultrasonic welding and the program was terminated.

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PREFACE

This report was prepared by Hughes Helicopters, Inc., under Contract DAAK51-79-C-0045 with the Applied Technology Laboratory (ATL), U.S. Army Research and Technology Laboratories (AVRADCOM), Fort Eustis, Virginia. The ATL technical monitor for this contract was Mr. R. Rodgers.

Sonobond Corporation, one of the leaders in ultrasonic welding technology, was a prime subcontractor for this program. Their efforts were primarily under the direction of Mr. R. Kramer. The Hughes Helicopters, Inc. project manager was Mr. Ken Niji, who prepared the final report.



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INTRODUCTION

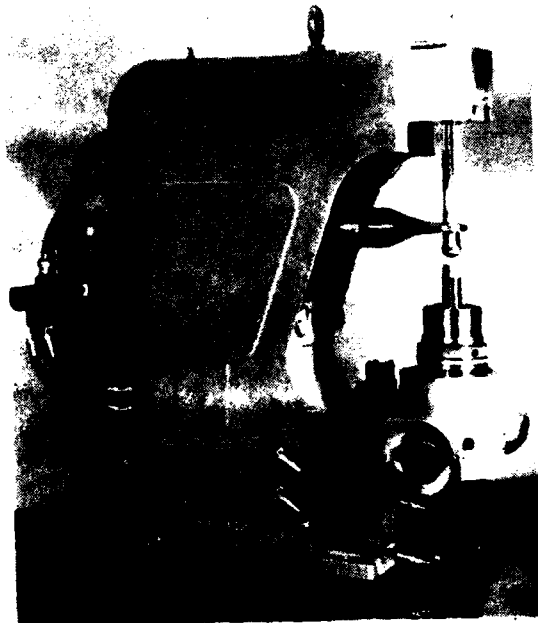
Hughes Helicopters, Inc. (HHI), with the assistance of Sonobond Corporation as a major subcontractor, has concluded a study of ultrasonic weld bonding, a new method for fabricating primary structural components for helicopters. This program followed a previously completed ultrasonic welding program involving secondary structures (Reference 1).

The previous program showed that ultrasonic welding could provide a viable, high-strength, low-cost method of fabrication applicable to secondary aircraft structures. The ultrasonic welding procedure was demonstrated to be effective for most aluminum alloys and some titanium alloys. In the welding procedure, the workpiece is clamped in place between the tip and anvil of the spot welder. The various parameters, such as input power and weld time, are set on the frequency converter power unit (see Figure 1). Welding occurs when the tip is made to oscillate in a plane parallel to the weld interface. The oscillating vibratory motion disrupts the oxide layers and other surface film on the mating surfaces, allowing solid-state bonding to occur. The fusion that takes place between mating surfaces occurs without formation of the cast nugget found in normal resistance spot welding.

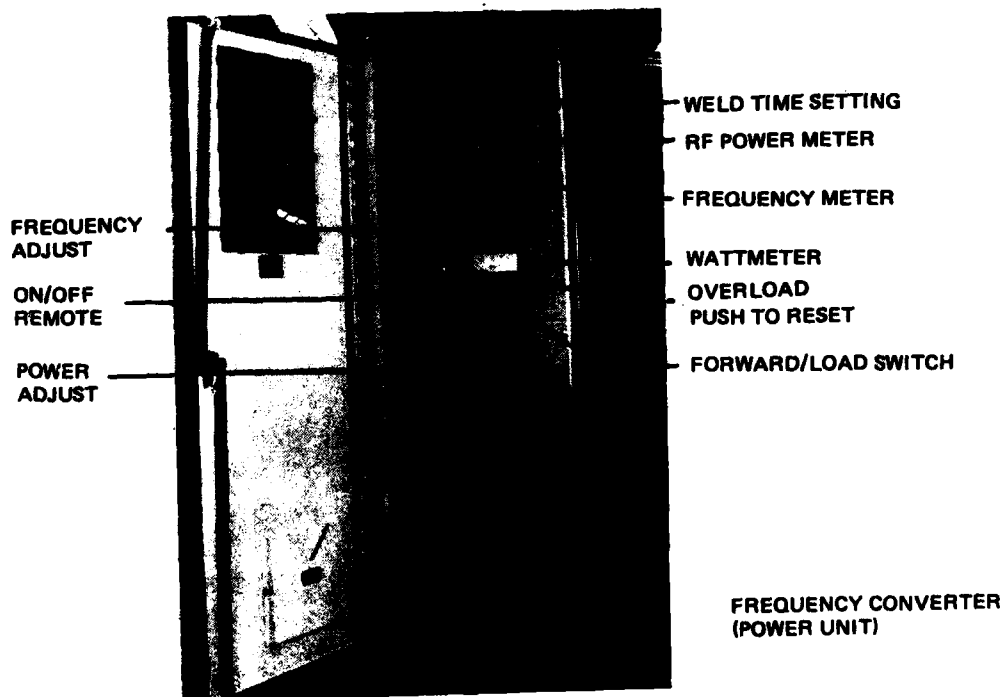
The weld bonding procedure involves a combination of ultrasonic welding and adhesive bonding. The vibratory motion of the welding tip displaces the adhesive between mating surfaces, allowing welding to occur. The welded assembly is then placed in an oven to cure the adhesive, thus completing the weld bond procedure.

The study to develop a new, reliable, cost-effective manufacturing technique attempted to provide an alternative to adhesive bonding and riveting, the methods currently used to produce structurally sound primary components in the aerospace industry. Adhesive bonding requires costly tooling and fixturing during the assembly process. Riveting requires extensive cost in time and labor, as well as adds a significant amount of weight to an assembled structure. New methods are constantly being investigated in an attempt to provide less costly manufacturing processes. Other programs have studied

1. Devine, J. and Dingle, G.K., ULTRASONIC WELDING OF HELICOPTER SECONDARY STRUCTURE COMPONENTS, Sonobond Corp. and Hughes Helicopters, Inc.; AVRADCOM R-77-8, US Army Aviation Research and Development Command, St. Louis, Missouri, October 1977.



ULTRASONIC SPOT WELDER



FREQUENCY
ADJUST

ON/OFF
REMOTE

POWER
ADJUST

WELD TIME SETTING

RF POWER METER

FREQUENCY METER

WATTMETER

OVERLOAD
PUSH TO RESET

FORWARD/LOAD SWITCH

FREQUENCY CONVERTER
(POWER UNIT)

Figure 1. Ultrasonic welding equipment.

weld bonding processes using resistance welds (References 2 and 3). In a similar manner, the intent of this program was to use the cost savings provided by ultrasonic welding and to apply it to a weld bonding process. The ultrasonic welds which hold the various subcomponents together, with adhesive in place, eliminate the need for complicated fixturing during the bonding process. The ultrasonic welds would also provide a strong structural backup to the bonded component.

The purpose of this program was to develop and optimize the ultrasonic weld bonding process, and after application to various test components, develop an implementation plan for its application on the Advanced Attack Helicopter (AAH) program. Various adhesives were considered before selecting the EA 9628 and FM 123-2u unsupported film adhesives for use in the study. A surface condition compatible to both ultrasonic welding and adhesive bonding (a primed and etched surface) was determined and used throughout. Testing consisted of static, fatigue, and accelerated environmental tests of coupons. Sonobond Corporation fabricated the test coupons, which were submitted to HHI for analysis. Coupon testing revealed problems with the bond quality between welds and with environmental degradation. Further attempts were made to correct these problems. However, environmental degradation of bond quality continued to occur, reducing weld bond strengths to weld strengths. It appears that the conditions required for bonding and welding may not be compatible enough to provide a sufficiently sound weld bonded part. Also, it seems that present control and monitoring capabilities may not be adequate for weld bonding purposes. Results of the tests are presented and discussed in this report.

2. Croucher, T.R., ADVANCED WELD BONDING PROCESS ESTABLISHMENT FOR ALUMINUM, Northrop Corp.; AFML-TR-79-4006, Wright Patterson AFB, February 1979.
3. Fields, D., RESISTANCE SPOT WELD ADHESIVE BONDING PROCESS, Lockheed-Georgia; RTDIT-8-279-(1), Wright Patterson AFB, October 1969.

DISCUSSION

This effort was originally planned as a five-phase program. Phase I involved selection of a structural component and process optimization; this included the selection of adhesive and surface treatments, followed by coupon fabrication and testing. Phase II involved fabrication and tool proofing of a test component. Phase III involved fabrication, test and evaluation of additional test components. Phase IV involved the development of an implementation plan for incorporation into the Advanced Attack Helicopter Program. Phase V involved the presentation of an industry/government briefing.

Initially, a primary structural AAH component had to be selected based on adaptability of the fabrication process, cost competitiveness, and structural performance. After consideration of several candidates, the wing flap was considered to be the most suitable. It consisted of several riveted joints and fittings, the bulk of which could be replaced by ultrasonic weld bonding. A major factor in the selection of this component was the minimal interface problems involved in the fit and function check of the item, required in Phase II of the program. After this candidate had been selected, a later design modification of the AAH eliminated the wing flap. After another review of the available candidates, the deck assembly was finally chosen as the most suitable remaining candidate. The assembly is a large component with many riveted attachments which could be assembled by the weld bonding procedure. Due to the impossibility of performing a fit and function test of such a part, those requirements were eliminated. It was decided that the assembly would be fabricated as a subcomponent, rather than as a whole, and would be subjected to localized testing which would provide data indicative of the effect on the total component.

The selected deck assembly was to be fabricated by ultrasonic weld bonding, which involves a combination of ultrasonic welding and adhesive bonding. It is a fabrication procedure intended to provide an easily manufactured, structurally sound part at lower cost. Riveting and adhesive bonding are presently the most common methods of manufacturing primary aircraft structures. However, the costs involved in production time and tooling have encouraged research toward finding alternative methods. Some previous weld bonding studies have used resistance welding (References 2 and 3). This program attempted to use the benefits of ultrasonic welding in the weld bonding process. The various aspects of ultrasonic welding have been examined and documented in studies conducted by Sonobond and Fairchild Republic (References 1 and 4).

4. Renshaw, T. et al. DEVELOPMENTS IN ULTRASONIC WELDING FOR AIRCRAFT, Fairchild Republic; Proceedings for 1979 National Sampe Tech. Conf. Vol. 11, November 1979.

In the weld bonding procedure, adhesive is placed between mating surfaces and the part is welded to hold the adhesive in place. The vibratory action on the welding tip displaces the adhesive between the surfaces, allowing welding to occur at that point. The assembly is then placed in an oven to cure the adhesive which results in the weld bonded component.

The welding machine used during this effort was a standard MH-1540 ultrasonic welder provided by Sonobond Corporation. The welder was equipped with a 15-kHz transducer, rated at 4.2 kilowatts for welding. A frequency converter (power source) was connected to the welder, which controlled input power and weld time (see Figure 1).

The primary concern of this program was to obtain an optimized ultrasonic weld bonding procedure that would provide adequate strength and durability. Various candidate adhesives and surface treatments were originally considered in an attempt to select an adhesive system to be used for the bulk of the test program.

Adhesive Systems Considered:

| <u>Film Adhesive</u> | <u>Primer</u> |
|----------------------|---------------|
| AF 163K | EC 3924B |
| FM 73 unsupported | BR 127 |
| FM 400 | BR 127 |
| EA 9628 | EA 9210 |
| FM 123-2u | EA 9210 |

The selected system would have to be compatible with both ultrasonic welding and adhesive bonding. The effect of different surface conditions (etched versus anodized) on ultrasonic welding was evaluated through some tensile shear tests of welded coupons.

Surface Condition Effect on Ultrasonic Welding (Without Adhesive):

| <u>Primer (Oven Cured)</u> | <u>Surface</u> | <u>Tensile Shear (lb)</u> |
|----------------------------|----------------|---------------------------|
| EC 3924B | Anodized | Not Weldable |
| BR 127 | Anodized | Not Weldable |
| BR 127 | Etched | Mean = 906 |
| | | Std. Dev. = 320 |
| EA 9210 | Anodized | Mean = 1466 |
| | | Std. Dev. = 250 |
| EA 9210 | Etched | Mean = 1668 |
| | | Std. Dev. = 179 |

Anodized surfaces were difficult to weld. The optimum surface condition, yielding the highest shear value with the least deviation, occurred with an etched surface using EA 9210 primer. The use of this surface preparation led to the use of the Hysol EA 9628 and American Cyanamid FM 123-2u film adhesives. (Early in the program, it was decided that for ease of handling and application, film adhesives should be used exclusively in this weld bonding effort.)

Using one of the selected adhesive-primer combinations, differences in adhesively bonded strengths due to surface conditions (etched versus anodized) were evaluated.

Surface Condition Effect on Adhesive Bonding
(Using EA 9210 Primer and FM 123-2u Adhesive, 0.030 psf):

| | <u>Tensile-Shear (psi)</u> |
|--|--------------------------------|
| 1. Etched with room temperature cured primer | 3645 |
| 2. Etched with oven cured (1 hr., 250°F) primer | 4125 |
| 3. Anodized with oven cured (1 hr., 250°F) primer | 4205 |

The data indicated that the use of an etched surface, as opposed to an anodized surface, would not significantly affect adhesively bonded strengths.

Welding parameters of power, time, and clamping force were also optimized to provide the highest strength. Initial welding of the panels revealed some difficulties with surface deformation and bulging tendencies between welds. These difficulties, which did not occur during normal ultrasonic welding, appear to have been caused by the higher power and clamping force required to weld through the adhesive film layer. To correct these problems, the tip configuration was altered from a series of concentric rings to a spherical tip. A hydraulic clamping fixture was developed and used to eliminate gaps in the bonded area between welds. (See Figures 2 through 6.)

Figure 2 illustrates the deep indentations left by the concentric ring tip configuration. Some warping of the panel edge can also be seen. Figure 3 shows the surface condition using the spherical tip configuration. The surface is smoother, with less deformation. Figure 4 is an edge view of the welded interface, clearly exhibiting bulging and deformation. The hydraulic clamping fixture shown in Figure 5 was used to eliminate the bulging problem.



Figure 2. Surface deformation due to concentric ring tip configuration.



Figure 3. Normal ultrasonic weld using spherical tip.



Figure 4. Edge view of the welded interface.

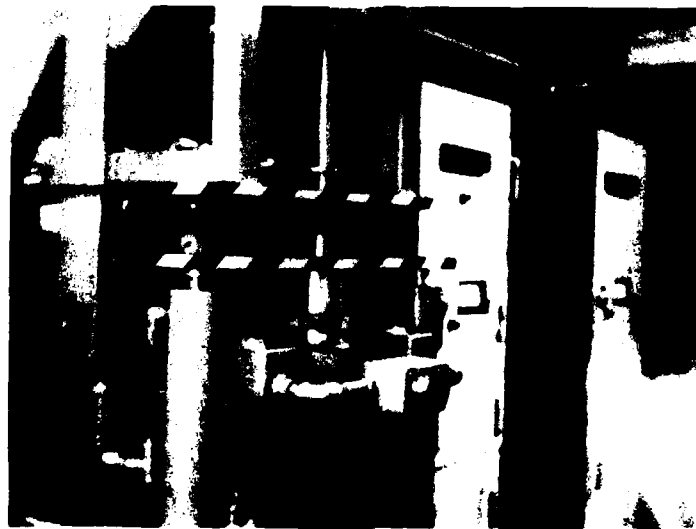


Figure 5. Hydraulic clamping fixture used to eliminate bulging.

The mating panels were placed between the clamping boards and held in place during welding. Use of the external clamping fixture, along with the spherical tip configuration, resulted in the smooth, uniform, weld bonded assembly shown in Figure 6.

The final optimized weld parameters of power, time, and clamp force required for weld bonding were determined to be 3200 watts, 0.50 second, and 275 psi, respectively.



Figure 6. Weld bonded panel using clamping fixture and spherical tip.

TEST PROCEDURES AND RESULTS

After the optimum surface preparation and welding parameters were determined, the coupon tests were conducted; the tests examined the adhesive bond quality, the weld quality, and the environmental effects. All of the tests were conducted using 5-inch by 7-inch by 0.040-inch-thick 2024-T3 Alclad aluminum alloy panels which were cut into 1-inch-wide coupons after fabrication. A summary of the weld bond coupon test conditions are presented in Table 1, and corresponding coupon configurations are shown in Figure 7. Coupon test results are presented in Table 2.

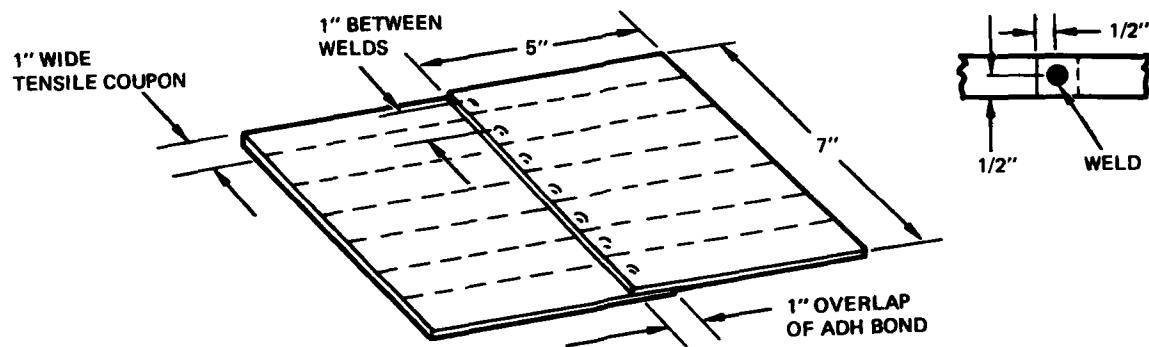
Conditions typical of the weld bond interface, where adhesive remnants exist within the weld zone and bits of clad material are entrapped within the adhesive zone, are illustrated in Figures 8 through 11. The results indicated that ultrasonic weld bonding achieved higher strengths than resistance welds, rivets, or ultrasonic welds when joining comparable sheet thicknesses. However, the adhesive bond in the area between welds was not able to achieve the standard strengths of a normal adhesive bond. In addition, the lack of adequate adhesion resulted in severe degradation in strength when exposed to a salt-spray environment. As a result, weld bond strengths were reduced to that of the ultrasonic weld during environmental tests.

The results of the coupon tests indicated that further work was required to resolve the problems encountered. An extension of the coupon test phase, directed toward correction of the problems, was then begun. All coupons fabricated in the extended coupon test phase (except for a set of adhesively bonded 0.090-inch panels) were made from 0.040-inch-thick 2024-T3 Alclad aluminum alloy panels. Test coupons used a 0.75-inch overlap (reduced from the 1-inch overlap used in previous tests), in an attempt to insure failure through the bond rather than through the substrate. All tests were conducted using both FM 123-2u and EA 9628 unsupported film adhesives. A list of the various tested conditions is presented in Table 3. Summary matrices of all the data are included in Tables 4 through 8, along with a discussion of the results.

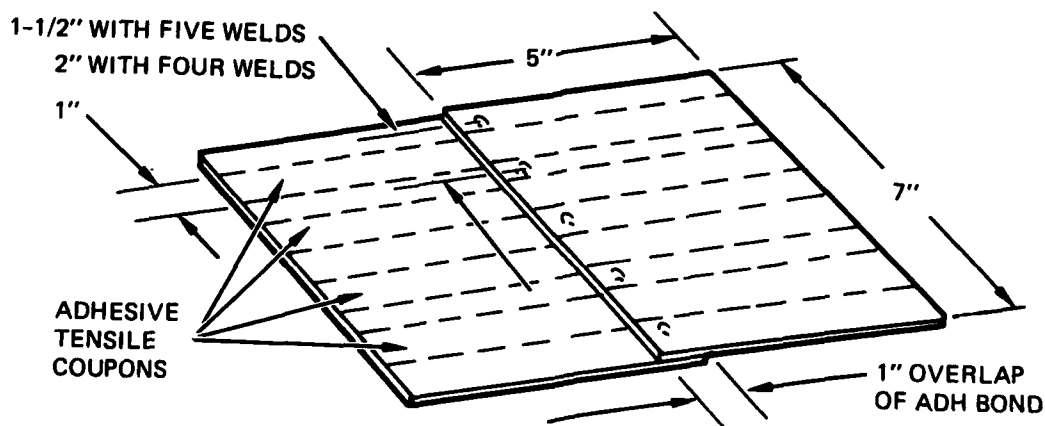
The test conditions formulated for the extended coupon tests (Table 3) attempted to identify and correct factors which may have caused undesirable results in the initial tests. Condition 1 addressed the effect of backing configurations in an effort to reduce peeling and distortion, which may have affected the test results. Condition 2 provided various adhesively bonded conditions for comparative purposes; the anodized and primed condition is normally used by HHI for adhesive bonding. Bonding with and without pressure was studied to determine its impact, since lack of pressure was

TABLE 1. WELD BOND COUPON TEST CONDITIONS

| Condition | Configuration | Tests | Adhesive | Purpose |
|-----------|-----------------------------------|------------------------------------|-------------------|--|
| A1 | Figure 7a | T-Shear Env. T-Shear Fatigue | Uncured EA 9628 | To evaluate weld quality through the adhesive. |
| A2 | Figure 7a | T-Shear Env. T-Shear Fatigue | Uncured FM 123-2u | To evaluate weld quality through the adhesive. |
| A3 | Figure 7a | T-Shear Env. T-Shear Fatigue | Cured EA 9628 | To evaluate weld bond quality. |
| A4 | Figure 7a | T-Shear Env. T-Shear Fatigue | Cured FM 123-2u | To evaluate weld bond quality. |
| B5a | Figure 7b (1-1/2-inch spacing) | T-Shear Env. T-Shear | Cured EA 9628 | To evaluate bond quality between welds. |
| B5b | Figure 7b (1-1/2-inch spacing) | T-Shear Env. T-Shear | Cured FM 123-2u | To evaluate bond quality between welds. |
| B6a | Figure 7b (2-inch spacing) | T-Shear Env. T-Shear | Cured EA 9628 | To evaluate bond quality between welds. |
| B6b | Figure 7b (2-inch spacing) | T-Shear Env. T-Shear | Cured FM 123-2u | To evaluate bond quality between welds. |
| C7 | Figure 7c | T-Shear | Uncured FM 123-2u | To evaluate the effect of minimal edge distance. |
| D8 | Figure 7d | T-Peel | Cured EA 9628 | Additional evaluation of bond quality between welds. |
| D9 | Figure 7d | T-Peel | Cured FM 123-2u | Additional evaluation of bond quality between welds. |

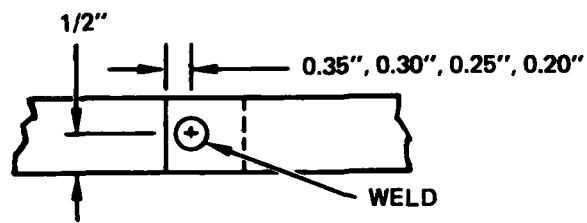


a. Used for conditions A1, A2, A3, and A4.



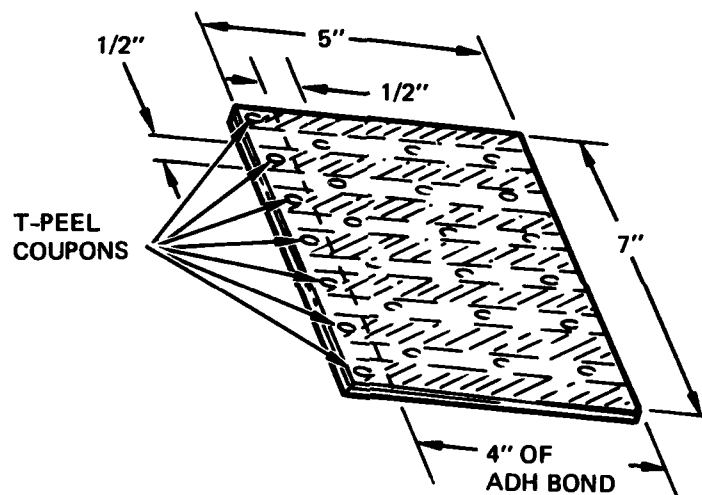
b. Used for conditions B5a, B5b, B6a, and B6b.

Figure 7. Test coupon configurations. (See Table 1)



1" WIDE TENSILE COUPON

c. Used for condition C7.

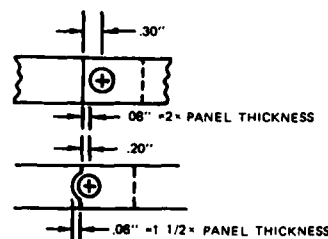


d. Used for conditions D8 and D9.

Figure 7. Test coupon configurations (continued). (See Table 1)

TABLE 2. WELD BOND COUPON TEST RESULTS

| Study | Condition (Table 1) | T-Shear (lb) | Env. T-Shear (lb) 10-Day Salt Spray | Fatigue |
|---|------------------------|--|--|--|
| Weld Quality | A1 | \bar{x} = 1266 σ = 66 | \bar{x} = 1310 \bar{x} = 1180 (30 days) | Failed at 859,630 cycles at 20.2 - 202 lb After 1×10^6 cycles at 13.5 - 135 lb After 3×10^6 cycles at 9 - 90 lb |
| | A2 | \bar{x} = 1217 σ = 85 | \bar{x} = 1380 \bar{x} = 1270 (30 days) | Failed at 54,300 cycles at 45.5 - 455 lb After 1×10^6 cycles at 30.3 - 303 lb After 1×10^6 cycles at 20.2 - 202 lb After 1×10^6 cycles at 13.5 - 135 lb After 3×10^6 cycles at 9 - 90 lb |
| Weld Bond Quality | A3 | Substrate Failure at 3360 | \bar{x} = 1320 | Failed at 330,000 cycles at 75 - 750 lb Failed at 1.19×10^6 cycles at 75 - 750 lb Failed at 246,370 cycles at 45.5 - 455 lb After 1×10^6 cycles at 30.4 - 304 lb After 1×10^6 cycles at 20.2 - 202 lb |
| | A4 | \bar{x} = 2956 σ = 424 | \bar{x} = 1275 | Failed at 637,470 cycles at 75 - 750 lb Failed at 583,530 cycles at 75 - 750 lb Failed at 56,180 cycles at 45.5 - 455 lb After 1×10^6 cycles at 30.4 - 304 lb |
| Some adhesive remnants were trapped in the weld zone and clad particles were dispersed into the adhesive area. | | | | |
| Bond Quality Between Welds | B5a | \bar{x} = 3040 σ = 375 | Fell apart Substrate to primer failure | |
| | B5b | \bar{x} = 2794 σ = 640 | \bar{x} = 1059 | |
| | B6a | \bar{x} = 2963 σ = 326 | | |
| | B6b | \bar{x} = 2344 σ = 392 | | |
| There was incomplete adhesion and little or no "primer to adhesive" contact midway between welds. | | | | |
| Edge Distance Effect | Sample C7 | \bar{x} = 906 | | |
| | | Minimum distance without panel distortion: | | |
| | | Minimum distance without panel cracking: | | |
| Bond Quality | D8 | T-Peel 12 piw (lb per inch width) | | 0% cohesive failure |
| | D9 | 11 piw | | 0% cohesive failure |
| 35 piw is required by HHI for adhesive bonding. All samples demonstrated substrate to primer failure. | | | | |
| \bar{x} = mean; σ = Std. Dev. | | | | |



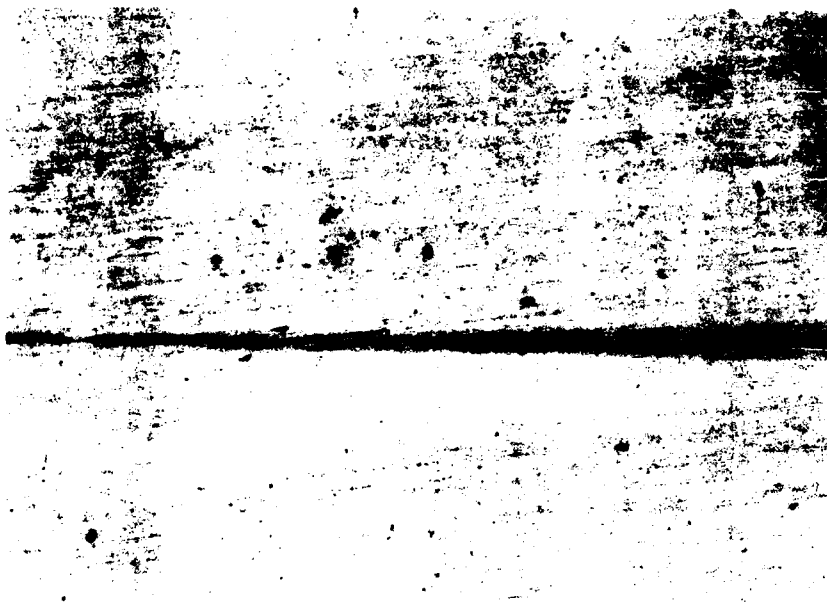


Figure 8. Cross section of weld zone
with entrapped adhesive.

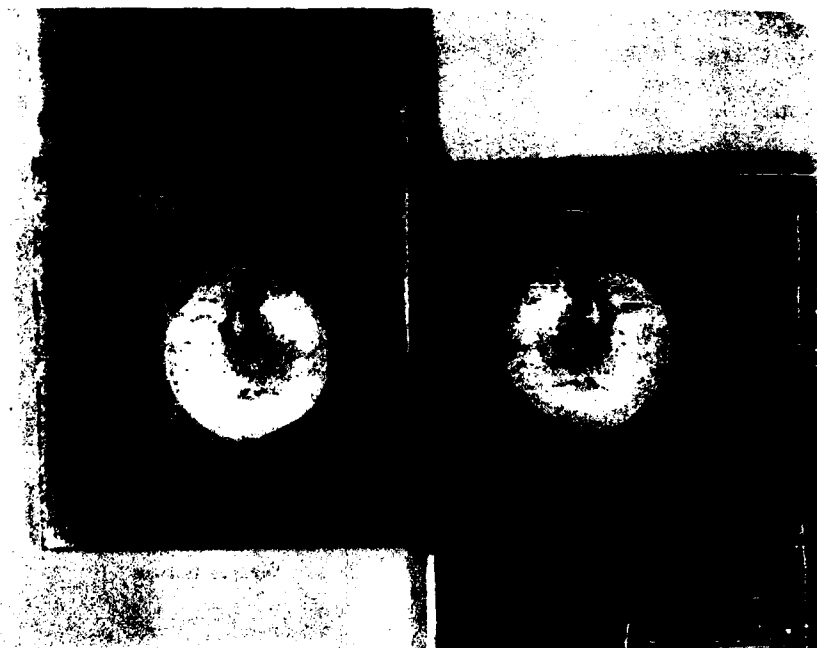


Figure 9. T-shear specimen with remnant
adhesive in weld zone.



Figure 10. Cross section of bond area between welds of 1-1/2-inch spacing.
(Note entrapped clad material.)



Figure 11. Cross section of weld bond interface.
(Clad and adhesive material has been forced out of weld zone into the adhesive area.)

TABLE 3. EXTENDED COUPON TEST

| Condition | Purpose | Configuration | Tests |
|-----------|--|---|------------------------------------|
| 1. | Effect of Backing Configuration (Adhesively Bonded Panels) | Etched and Primed: <ul style="list-style-type: none"> - Under Dead Load - Unbacked 0,090-inch-thick panels - Double balanced - Double unbalanced <ul style="list-style-type: none"> - Under 35 psi - Unbacked 0,090-inch-thick panels - Double balanced - Double unbalanced | T-Shear Env, T-Shear |
| 2. | Analysis of Different Adhesive Bond Conditions | Anodized and Primed: <ul style="list-style-type: none"> - Under Dead Load - Under 35 psi Etched and Primed: <ul style="list-style-type: none"> - 2 Layers of FM 123-2u - Under dead load - Under 35 psi - Sonobond Adhesive Bonded - Under dead load | T-Shear Env, T-Shear |
| 3. | Effect of Reducing Overlap from 1,0 inch to 0,75 inch | Same weld bond conditions as in original effect, but using 0,75-inch overlap. | T-Shear Env, T-Shear |
| 4. | Effect of Solvent Wipe Prior to Fabrication | Weld bond after solvent cleaning of panels (0,75-inch overlap) | T-Shear Env, T-Shear Fatigue |
| 5. | Effect of Applying Dead Load During Curing | Weld bonded panels solvent cleaned. 0,75-inch overlap. Dead load during curing. | T-Shear Env, T-Shear Fatigue |
| 6. | Effect of Thicker Film (Double Thickness) | Weld bonded panels solvent cleaned. 0,75-inch overlap. Double adhesive thickness. | T-Shear Env, T-Shear Fatigue |
| 7. | Effect of Applying Higher External Clamping Force During Welding | Weld bonded panels solvent cleaned. 0,75-inch overlap. External clamping force. | T-Shear Env, T-Shear |

TABLE 4. ADHESIVE BOND SUMMARY MATRIX
(CONDITIONS 1 AND 2) T-SHEAR (PSI)

| | FM 123-2u Film Adhesive | | | | EA 9628 Unsupported Film Adhesive | |
|---|------------------------------------|---------------------------|----------------|--------------|---|---------------|
| | One Layer | | Two Layers | | Dead Load | 35 PSI |
| | Dead Load | 35 PSI | Dead Load | 35 PSI | | |
| Double Unbalanced (Etched and Primed) | Sonobond | \bar{x} 3790 s (440) | 3040 (1375) | | 4675 (185) | |
| | HHI | \bar{x} 3455 s (600) | 5181 (250) | 4430 (90) | 4810 (385) | 5590 (160) |
| | HHI (Previous Config. Study) | \bar{x} 4670 s (90) | | | 5040 (260) | |
| Double Balanced (Etched and Primed) | HHI | \bar{x} 3520 s (230) | 4030 (125) | | 3695 (275) | 3830 (150) |
| | HHI (Previous Config. Study) | \bar{x} 3490 s (120) | | | 3845 (75) | |
| Double Unbalanced (Anodized and Primed) | HHI | \bar{x} 5500 s (165) | 5380 (100) | | 6290 (385) | 5300 (250) |
| Single 0.090 inch Panels (Etched and Primed) | HHI | \bar{x} 3940 s (195) | 4395 (230) | | 4415 (410) | 4080 (275) |
| \bar{x} = mean; s = standard deviation | | | | | | |

TABLE 5. ADHESIVE BOND SUMMARY MATRIX (CONDITIONS 1 AND 2)
T-SHEAR (PSI), 10-DAY SALT-SPRAY

| | FM 123-2u Film Adhesive | | | | EA 9628 Unsupported Film Adhesive | |
|---|------------------------------------|--------------|--------------|--------------|--|--------------|
| | One Layer | | Two Layers | | Dead Load | 35 PSI |
| | Dead Load | 35 PSI | Dead Load | 35 PSI | | |
| Double Unbalanced (Etched and Primed) | Sonobond | 0 | 0 | | 0 | |
| | | 0 | 0 | | 1715 | |
| | HHI | 1410 1420 | 0 200 | 2140 1985 | 3560 3020 | 3700 3040 |
| Double Balanced (Etched and Primed) | HHI (Previous Config. Study) | | | | | |
| | HHI | 895 1080 | 5130 2565 | | 480 0 | 725 1000 |
| | HHI (Previous Config. Study) | | | | | |
| Double Unbalanced (Anodized and Primed) | HHI | 5775 5275 | 5265 5140 | | 5335 5470 | 5550 5185 |
| | HHI | 270 1020 | 0 0 | | 1805 800 | 0 0 |
| NOTE: Numbers denote actual T-shear values. | | | | | | |

**TABLE 6. WELD BOND SUMMARY MATRIX
T-SHEAR (PSI)**

| Condition | Bond Area | FM 123-2u \bar{x} (s) | EA 9628 \bar{x} (s) |
|---|---------------|----------------------------|--------------------------|
| 3 | Around Welds | 4099 (425) | 4980 (235) |
| | Between Welds | 4095 (220) | 4160 (695) |
| 4 | Around Welds | 4815 (310) | 4945 (420) |
| | Between Welds | 3980 (395) | 4365 (460) |
| 5 | Around Welds | 4855 (470) | 5705 (390) |
| | Between Welds | 4425 (565) | 5035 (275) |
| 6 | Around Welds | 5285 (210) | 6770 (575) |
| | Between Welds | 4530 (195) | 5435 (165) |
| 7 | Around Welds | 3995 (225) | 6655 (360) |
| | Between Welds | 4330 (135) | 4385 (85) |
| \bar{x} = mean s = standard deviation NOTE: For calculation of strength around welds, the weld area (~0.15 sq. in.) was subtracted from the total overlap area; adhesive contribution only. | | | |

**TABLE 7. WELD BOND SUMMARY MATRIX
T-SHEAR (PSI), 10-DAY SALT-SPRAY**

| Condition | Bond Area | FM 123-2u | EA 9628 |
|---|------------------|--------------|--------------|
| 3 | Around Welds | 1830 2050 | 1420 1965 |
| | Between Welds | 310 0 | 0 0 |
| 4 | Around Welds | 2025 1845 | 1710 2645 |
| | Between Welds | 0 390 | 665 20 |
| 5 | Between Welds | 1660 1935 | 1230 1855 |
| | Around Welds | 0 0 | 970 0 |
| 6 | Between Welds | 2375 2280 | 1475 2475 |
| | Around Welds | 0 195 | 0 0 |
| 7 | Around Welds | 1810 1465 | 1760 2620 |
| | Between Welds | 267 0 | 0 0 |
| NOTE: Numbers denote actual T-shear values. | | | |

TABLE 8. FATIGUE DATA (BETWEEN WELDS)

| Condition | Adhesive | Sample No. | Failed: | No. Cycles | Max. Stress (PSI) |
|--|-----------|-----------------|---|-----------------|-------------------|
| 4 | EA 9628 | 1 | at | 21,800 | 1265.62 |
| | | | after | 1×10^6 | 843.75 |
| | | | after | 1×10^6 | 562.5 |
| | | | after | 1×10^6 | 375. |
| | 2 | at | 827,630 | 843.75 | |
| | | after | 1×10^6 | 562.5 | |
| FM 123-2u | 1 | at | 161,960 | 843.75 | |
| | | after | 1×10^6 | 562.5 | |
| 5 | EA 9628 | 1 | at | 20,590 | 1265.62 |
| | | | after | 1×10^6 | 843.75 |
| | | | after | 1×10^6 | 562.5 |
| | FM 123-2u | 1 | at | 65,570 | 843.75 |
| 6 | EA 9628 | 1 | at | 75,720 | 1265.62 |
| | | | after | 1×10^6 | 843.75 |
| | | | after | 1×10^6 | 562.5 |
| | | 2 | at | 241,830 | 1265.62 |
| | | | after | 1×10^6 | 843.75 |
| | | | after | 1×10^6 | 562.5 |
| | after | 1×10^6 | 375. | | |
| | | FM 123-2u | 1 | at | 15,110 |
| | after | 1×10^6 | 562.5 | | |
| Specification: | | | | | |
| EA 9628 (HMS 16-1111) | | | 1340 PSI \pm 1100 for 0.5×10^6 cycles (2440 PSI max) | | |
| FM 123-2u (HMS 16-1069) | | | 1250 PSI \pm 1000 for 1×10^6 cycles (2250 PSI max) | | |
| (Federal Specification MMMA-132 for FM 123-2u is 1×10^6 cycles at 75-750 PSI) | | | | | |

suspected to be one cause of insufficient bonding between welds. Condition 3 provided a comparison with the weld bonding results of the initial tests. Condition 4 was to determine whether a cleaner surface would help improve bonding. Conditions 5 through 7 were various approaches for correcting the inadequacy of the bond between welds. Environmental samples from each condition were studied to determine the factors that would help maintain the bond in a salt-spray environment. In addition, a few tests were conducted to determine the effect of certain conditions on fatigue.

Tables 4 through 8 show the results obtained from the various test conditions. The T-shear values of the adhesive bond conditions (1 and 2) are shown in Table 4, with corresponding environmental data presented in Table 5. The double unbalanced backing configuration tended to give the most satisfactory failure of the bond, without cleavage or distortion. Application of curing pressure resulted in higher bond strengths. The anodized and primed surfaces resulted in the strongest adhesive bonds, and the environmental tests (Table 5) indicate that they were the only ones able to retain strengths.

Table 6 shows the weld bond T-shear obtained in Conditions 3 through 7, with corresponding environmental data given in Table 7. The T-shear strengths obtained for these weld bonded coupons tend to be higher than the values obtained previously. The shear values obtained for Conditions 5 and 6 appear to be about as good as those for a purely adhesive bond. This may be due to the added pressure (presence of dead load for Condition 5, or thicker film which possibly creates greater pressure in Condition 6). This would be consistent with the finding that higher adhesive bond strengths are obtained with application of pressure during cure.

The environmental samples of all the weld bond conditions resulted in a manner consistent with previous studies. The coupons containing the welds appear to have reduced in strength down to the weld strengths. The coupons between welds continue to fall apart, unable to maintain the bonds and prevent moisture penetration. The environmental coupons between the welds failed in a manner similar to the etched and primed adhesively bonded coupons exposed to the salt spray.

Results of selected fatigue tests shown in Table 8 indicate that the bonds formed between welds are not as good as those formed through normal adhesive bonding procedures. The coupons tested fell short of HHI required stress levels specified for the adhesives.

After reviewing the results of Conditions 1 through 7, it became apparent that surface condition (anodized rather than etched) was the key factor in obtaining and maintaining good bonding. The following discussion describes each of the various test configurations.

CONDITION 1

The effect of different backing configurations was determined using only adhesively bonded coupons. Earlier, an investigation was conducted involving various backing configurations in an attempt to determine one which would result in the least cleavage and the least local deflection. The previous configuration study showed that the highest loads and the least cleavage and deflection occurred for the double unbalanced configuration using a 0.090-inch-thick backing. A comparison study between the double balanced and double unbalanced configurations was repeated, with the effect of cure pressure application and environmental exposure also being determined.



0.090 " DOUBLE UNBALANCED



DOUBLE BALANCED

Again, the double unbalanced configuration seemed to give better results.

CONDITION 2

Using the double unbalanced backing configuration, various adhesive bond comparisons were made. The values of the T-shear specimens adhesively bonded by Sonobond were generally comparable to those obtained by HHI. The discrepancy involving the double thickness of FM 123-2u adhesive was due to gaps existing between the two layers of adhesive in Sonobond's sample. A set of anodized and primed panels were bonded for comparison with the etched and primed panels. A set of unbacked 0.090-inch panels were also bonded for comparison.

Panels were adhesively bonded under both a dead load and a curing pressure of 35 psi for comparison. Test results indicate that higher adhesive bond strengths are obtained when curing pressure is applied. Generally, whenever the data reflected the opposite, it was due to the occurrence of thinner bond lines under curing pressure. The EA 9628 film appeared less sensitive to the effect of curing pressure.

Environmental samples, taken from each situation, were exposed to a 10-day salt spray. Results show that the anodized and primed panels were the only ones able to retain strengths after salt-spray exposure. A thin, even bond

line is displayed, with good cohesive failure. Coupons that fell apart after the salt spray displayed complete adhesive failure, with separation occurring between the primer and panel. Coupons retaining some strength typically displayed adhesive failure, although some portion of the film remained attached to the mating surface.

CONDITION 3

For Conditions 3 through 7, 5-inch by 7-inch panels were weld bonded by Sonobond using both FM 123-2u and EA 9628 unsupported film adhesives. The weld bonded panel configuration remained the same as in the original coupon phase, except for the use of the 0.75-inch overlap and the 0.090-inch double unbalanced backing system. All conditions were tested for the adhesive bond quality around the weld (1-inch-wide coupons containing the weld) and for the bond quality between welds (1-inch-wide coupons taken between welds). Environmental samples were taken again from each situation for exposure to a 10-day salt spray. Also, selected samples between welds were fatigue tested to determine bond quality.

For Condition 3, the conditions used for the initial coupon fabrication were repeated, as a comparison of the 0.75-inch overlap to the 1-inch overlap. The data indicates a significant increase in strengths (~20%) compared to previous results. This is basically due to less distortion (and less peeling effect) experienced by our present coupon configuration.

CONDITION 4

The effect of cleaning the panels with a solvent wipe, prior to weld bonding, was studied to see if a better bond between welds could be achieved. This procedure did not appear to have much significance. (Conditions 5 through 7 included solvent wiping of panels prior to weld bonding.)

CONDITION 5

The effect of applying a small dead load between welds during the cure cycle was studied. This appeared to aid the bond strength between welds.

CONDITION 6

A double thickness of film was used to determine its effect on bond qualities. It appears that the thicker film may create greater pressures and reduce voids between welds during the weld sequence, thus resulting in higher bonding strengths.

CONDITION 7

Application of a higher external clamping force during welding (through FM 123-2u adhesive) yielded inconclusive results. Studying the bond failure surfaces did not reveal any unusual pattern or explanation. In the case of EA 9628, the increased outside clamping force increased the strength around the weld areas, but it did little to increase strengths between welds.

The data indicates that an anodized surface is important in resisting environmental degradation. The etched and primed panels all displayed degradation of strength ranging from considerable to complete. However, early attempts to ultrasonically weld through an anodized surface proved futile, thus resulting in weld bonding efforts through an etched and primed surface.

In an effort to allow ease of implementation in conducting the program, typical HHI bath and surface treatments were used. Film, rather than paste, adhesive was also used to provide easy application and implementation.

The consistent environmental degradation of HHI weld bonded specimens suggests the use of special baths and surface treatment used by Fairchild/Northrop in their successful resistance weld bond study, which displayed no environmental problems (References 2 and 5). Their preparation involves an anodize (using different voltage and solution), a special cleaning solution, and a special weld bond paste adhesive (Goodrich 1444B).

The thickness of the anodize used by Fairchild/Northrop in their studies is much thinner than the HHI anodize thickness. Before attempting to apply their procedures (using their materials and solutions), a determination of the effect of anodize thickness on ultrasonic weldability is desired.

It should also be noted that the Fairchild/Northrop resistance weld bonding program used equipment that enabled them to control the entire weld cycle. Controlled use of current and force enabled precise monitoring of weld initiation and expansion. Use of a microprocessor allowed repeatable feedback control on a cycle-by-cycle basis for consistent welding through the treated surfaces.

It appears that present control and monitoring capabilities of the ultrasonic welder may not be adequate for weld bonding purposes. Ultrasonic welding is very sensitive to surface condition. Unless the three critical variables of frequency, power, and force can be controlled and monitored more accurately, and with relative ease, it appears that ultrasonic weld bonding would be difficult to accomplish.

5. Bowen, B. B. et al., IMPROVED SURFACE TREATMENTS FOR WELD BONDING ALUMINUM, Northrop Corp.; AFML-TR-76-159, Wright Patterson AFB, October 1976.

CONCLUSIONS

Results of the initial set of coupon tests indicated that further work was required to improve bonding characteristics of the ultrasonic weld bond operation. An extended coupon test phase was then conducted in an attempt to improve the quality of bonding between welds and the environmental durability of the bonds. After studying various conditions, the following conclusions can be drawn:

- The surface conditions for adhesive bonding and ultrasonic welding appear to be incompatible. The anodized surface conducive to adhesive bonding appears to be unweldable. Conversely, the etched surface conducive to welding is subject to environmental degradation.
- Application of pressure during cure results in higher bond strengths. Use of thicker film (double thickness of 0.006-inch FM 123-2u and double thickness of 0.010-inch EA 9628) appears to provide some added pressure.
- The ultrasonic welding equipment requires greater control and monitoring capabilities regarding frequency, power, and force for weld bonding application.

RECOMMENDATIONS

Based on the results of this effort, it is recommended that:

- Variations in anodize solutions and thicknesses be studied to determine whether welding can take place through some type of anodized surface.
- Improvements be made on the welding equipment to make it more applicable to weld bonding. Additional equipment to control and monitor the weld sequence should also be used.

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